Proceedings of the 5th WSEAS International Conference on Signal Processing, Istanbul, Turkey, May 27-29, 2006 (pp243-248)

Optimum Setting of Active Filter Parameters By Using Genetic Algorithms

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Abstract: - The aim of this paper is computing of the optimum duty cycle and inductance using Genetic Algorithm to minimize tracking error and operating costs by means of a new current reference. Such a current reference is able to share the responsibilities in power quality deterioration between supply and customer, making the filter to deliver a current with a lower harmonic content, which means a lower power delivered and a lower switching frequency. The use of different control approach may be helpful to achieve a good current control since this approach allows to carry out a control action independent from the electrical parameters.

Key-Words: - Active filter, Optimum, Genetic Algorithm, Crossover

1 Introduction

Traditionally, passive filters have been used to eliminate line current harmonics and to improve the load power factor. However, in practical applications these passive second-order filters present many disadvantages such as aging and tuning problems, series and parallel resonance, and the requirement to implement one filter per frequency harmonics that needs to be eliminated. In order to overcome these problems, different kinds of active power filters, based on force-commutated devices, have been researched and developed [1], [2]. Particularly, shunt active power filters, using different control strategies, have been widely investigated. They have gradually been recognized as a viable solution to the problems created by high-power nonlinear loads [3], [4]. These filters operate as current sources, connected in parallel with the nonlinear load, and generate the current harmonic components required by the load. In this form the mains only needs to supply the fundamental, avoiding contamination problems along the distribution lines. However, shunt active filters present the disadvantages that are difficult to implement in large scale, the control is complicated [5], [6], and the cost is high. One of the issues most of the researchers agree upon is that non-linear loads should not be considered the only responsible of the detrimental effects related to power systems in the distorted conditions, but the responsibility for the power quality deterioration should be shared between supply and customer [7]. In control applications, calculus_based optimization schemes are often employed to seek for optimal control gains to meet the performance requirements.

Genetic algorithms (GAs) are stochastic search techniques deriving inspiration from the principles of natural evolution and population genetics. GAs are versatile optimizers, and require minimal *a priori* assumptions on the nature of the problem. In contrast with other search strategies, GAs do not require differentiability, continuity, or other restrictive hypotheses on the objective function. Thus, they well lend themselves also to practical performance-oriented control design problems [8].

The aim of this work is to minimize tracking error and operating costs by select of optimum duty cycle and coupling inductance with the GA by means of current reference.

2 Computation current reference

Main task in designing an active filter control is to synthesis the current reference waveform for the PWM inverter. A shunt configuration is shown in Fig.1.

At the metering section only the voltage and current waveforms, both network conditions and load operating condition are responsible for, can be measured. It is not possible to know anything about the supply_side or the load_side of the same section. Independently from what there is really at the load_side,a load that shows a linear behavior represents an ideal load condition. In fact, if the load under test were linear, the supply system would be the only responsible for the power quality deterioration at the PCC. Therefore, in order to define a current reference, first of all it is necessary to fix ideal load condition [9]. Since the transfer of reactive power does not allow the current to be in phase with the corresponding voltage waveform, it is possible to suppose that an ideal linear load should absorb only an active power. This ideal load condition can be modeled using a simple resistance R. In this case, the parameter R of the ideal load has been calculated supposing that it absorbs only an active power at the fundamental frequency equal to the fundamental active power really flowing through the metering section. The evaluation of the parameter R allows to identify that part of the real load which represents an equivalent linear load and that does not influence the power quality (see Fig 2).

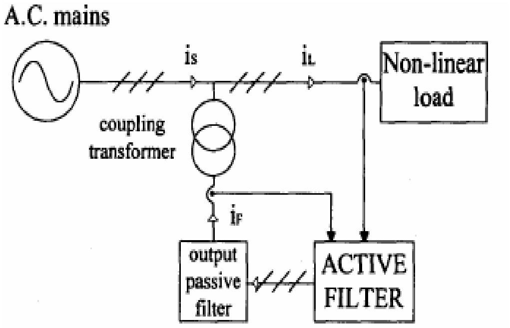

Fig.1: Proposed shunt APF topology

This part of the real load absorbs the active current which is the ideal current and represents only a part of the total current flowing through the metering section. This current has the same waveform of voltage and is always in phase with it.

The parameter R of the ideal load has been calculated following this procedure:

$$R = \frac{V_1}{I_{R_1}} = \frac{V_1}{I_1 \cos\phi_1} \qquad (1)$$

Where V_1 and I_1 are the fundamental value of the voltage and current at the PCC and ϕ_1 is the displacement angle between them. I_{R_1} represents the part of the fundamental current in phase with the fundamental voltage.

The ideal active current is:

$$i_A(t) = \frac{v(t)}{R} \qquad (2)$$

and the reference current is defined as:

$$i_{REF}(t) = i(t) - i_A(t) \qquad (3)$$

Where $v(t)$ and $i(t)$ represent voltage and current waveform at the PCC before compensation.

Let's consider a traditional current reference:

$$i_{REF_{trad}}(t) = i(t) - I_1 \cos\varphi_1 \sin(wt + \theta_1) \qquad (4)$$

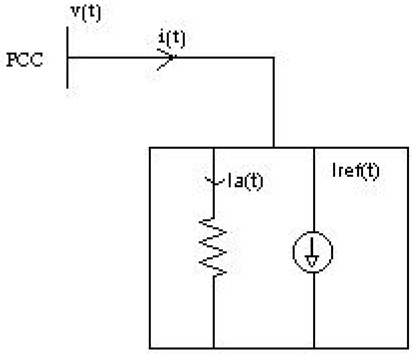

Fig.2: Nonlinear load connected to the grid, current component.

Where θ_1 represents the phase angle of the fundamental voltage.

It is possible to show that the new current reference has a lower harmonic content. In fact considering the Fourier series of the voltage $V(t)$:

$$\begin{aligned}
i_{REF}(t) &= i(t) - \frac{v(t)}{R} = \qquad (5)\\
& i(t) - \sum_{k=1}^{\infty} \frac{V_k}{R} \sin(kwt + \theta_K) = \\
& i(t) - \sum_{k=1}^{\infty} I_{Rk} \sin(kwt + \theta_K) = \\
& i(t) - \sum_{k=1}^{\infty} I_k \cos\varphi_k \sin(kwt + \theta_K) = \\
& i(t) - I_1 \cos\varphi_1 \sin(wt + \theta_1) - \sum_{k=2}^{\infty} I_K \cos\varphi_k \sin(kwt + \theta_k) \\
& = i_{REF_{trad}}(t) - \sum_{k=2}^{\infty} I_K \cos\varphi_k \sin(kwt + \theta_k)
\end{aligned}$$

since the principle of superposition can be applied [10].

3 Current control

Control of inverter switching allows the independence of electrical parameters, and it can be easily managed during its development. Genetic Algorithm computes the optimum duty cycle depending on the feedback signals and the coupling inductance.

The proposed current control criteria ensures a fixed_frequency driving signal. In each switching period current controller generates a duty cycle value which reduces the tracking error at the end of the interval. The following analysis leads to an analytical expression of the duty cycle as function of feedback signals.

In Fig.3 filtering and reference currents are depicted during a switching period, T_s.

They are represented as segments of a line due to the shortness of this interval in respect to fundamental harmonic. If tracking error is to be zero by the end of the interval, the following relation holds:

$$\Delta I_{ref} + err = \Delta i_1 + \Delta i_2 \qquad (6)$$

Where ΔI_{ref} is the change of reference current during T_s. err is the tracking error and Δi_1 and Δi_2 are the filtering current variations during the two complementary states of the switches (Fig.3)

In order to highlight filtering and reference current slopes the following relations hold:

$$\Delta I_{ref} = s^* T_s \qquad (7)$$

$$\Delta i_1 = s_1 D T_s$$

$$\Delta i_2 = s_2 (1-D) T_s$$

Where s_1 and s_2 are two slopes of filtering current during the switching period T_s, s^* is reference current slope and *D* is the duty cycle.

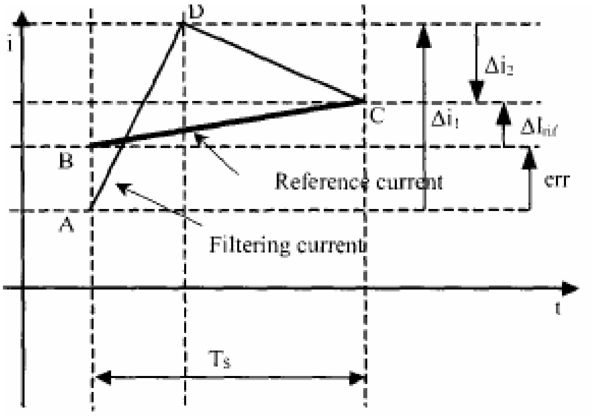

Fig.3: Reference and filtering current during a sampling period of active filter [11]

Reference current slope s^* is a feedback quantity while s_1 and s_2 are related to d.c. bus and line phase voltages by means of the coupling inductance:

$$s_{1/2} = \frac{\pm V_{dc} - V_{ph}}{L_F} \qquad (8)$$

By replacing (7) and (8) in (6) the following equation is obtained:

$$err = \{ \frac{(2D-1)}{L_F} * V_{dc} - \frac{V_{ph}}{L_F} - s^* \} * T_s \qquad (9)$$

Equation (9) substitutes the expertise which generates a cost function.

4 Genetic Algorithm Implementation

GAs are adaptive systems inspired by natural evolution. Genetic algorithms are belonging to guided random search techniques, which try to find the global optimum. J. H. Holland presented this concept in early seventies. The power of Genetic algorithms and other similar techniques (simulated annealing, evolutionary strategies) lies in the fact that they are capable to find global optimum in multi modal spaces (spaces with many local optimums). Classical gradient methods will always gravitate from starting position to some local optimum, which could also be global, but it can not be determinated for certain. Genetic algorithms are working with the set of potential solutions, which is called population. Each solution item (individual) is measured by fitness function. The algorithm can select individuals with better genetic materials for producing new individuals and further generations.

The simulation of evolution allows survival of better individuals and extinction of inferior ones. Evolution's goal is to find better individuals in each generation. The process of evolution is maintained by selection, crossover and mutation. In terms of genetic algorithms those processes are called genetic operations. The selection chooses superior individuals in every generation and assures that inferior individuals extinct. The crossover operator chooses two individuals from current population (parents) and creates a new individual (child) based on parents' genetic material. Selection and crossover operators will expand good features of superior individuals through the whole population. They will also direct the search process towards a local optimum. The mutation operator changes the value of some genes in an individual and helps to search other parts of problem space.

The program uses eliminating selection, which chooses and eliminates bad individuals from the current population, making room for new children that will be born from the remaining individuals. The probability of elimination increases proportionally with the fitness value of the individual. As the remaining individuals are better than the average of the population, it is expected that their children will be better as well.

There is some probability (through very small) that eliminating selection deletes the best individual. That would ruin the algorithm efforts and put its work back for some number of generations. Therefore, protection mechanism for best individuals has to be made, so the good genetic material is sustained in population. It is called the elitism. The authors' choice was to keep just the top one individual.

The reproduction operators constitute a very important part of genetic algorithms. Those operators make use of good individuals (which remained in population after selection) and construct new, better individuals and overall population.

The crossover operator operates on individuals (called parents) and make new, child individual from their genetic material. This operator fills up empty places in population that remained after elimination. If parents are good, it is likely that their child will also be good.

Uniform crossover operator was chosen as the best option for this problem.

```
for each gene in (parent1, parent2)
IF
(parent1[gene]==parent2[gene])
child[gene]=parent1[gene];
ELSE
child[gene]=random(parent1,parent2)[gene];
```

Uniform crossover operator checks all genes of both parents. If parents have equal values of a gene, this value is written to the child. If values from parent genes differ, then the algorithm randomly chooses one parent as a dominant one and takes its gene.

The program uses simple roulette wheel weighting selection algorithm. The probability of selection of one individual is proportional to it's fitness value.

The cost function is written as the negative of the Fitness value in order to put it into the form of a minimization algorithm:

$$\cos t = \{\frac{(2D-1)}{L_F} * V_{dc} - \frac{V_{ph}}{L_F} - s^*\} * T_s$$

The mutation is also a typical operator for the genetic algorithm. It takes one or more genes from an individual and changes its value.

5 Improving genetic algorithm behavior

The first step of the improved crossover operator simply copies equal genes from parents to the child individual. No additional conflicts can be added through copying those equal values. Different parent's genes are specially marked and delegated for further processing. In the second step, the crossover operator checks the list of equations for each marked gene in child individual and counts the number of potential conflicts generated for both parent's choices. The gene from a parent that generates fewer conflicts is chosen, so no additional conflicts are generated in addition to the conflicts caused by the parents.

```
for each gene in (parent1, parent2)
IF
(cost(parent1[gene])==cost(parent2[gene]))
child[gene]= random(parent1,parent2)[gene];
IF
(cost(parent1[gene])<cost(parent2[gene]))
child[gene]=parent1[gene];
IF
(cost(parent2[gene])<cost(parent1[gene]))
child[gene]=parent2[gene];
```

Such a modification was not introduced to the mutation operator. Similar functionality of the mutation operator would probably lead the whole population to the local optimum. In most cases the mutation operator generates inferior individuals, but most of its genes are good. Mutated genes help us to explore other parts of searching space and to avoid reaching of local optimum value.

Additional conflicts in population will be generated when two equal individuals appear in the mating process as parents. In that case one of the parents will be mutated and the child will be randomly generated. In this procedure a bad child individual will be created, but it will not spoil the population. Quite the reverse, it will bring new genetic material to the saturated population.

6 Simulation Results

Genetic Algorithm tool is applied for 10 different value of mutation rate from 0.02 to 0.2 by step 0.02. Table.1 compares costs for three types of crossover (Single crossover (SX), uniform crossover (UX) and modified uniform crossover (MUX)). It is considered that the most number of minimum cost value happens for MUX and SX. Parameter values of duty cycle and coupling inductance for above mutation rate values from 0.02 to 0.2 and three types of crossover have been shown in Table.2. Optimum values for duty cycle is 0.995 and coupling inductance is 10.

Fig.4 compares cost value of three types of crossover versus different mutation rate. By the way, the evolution of two parameters (Duty cycle value and coupling inductance) and instance of cost value are illustrated in Fig. 5, Fig. 6 and Fig.7 respectively.

7 Conclusion

In this study, the optimum duty cycle and inductance is computed using the Genetic Algorithm to minimize tracking error and operating costs by means of a new current reference. The algorithms with modified uniform crossover perform better than uniform crossover. Faster convergence is achieved in shortest time.

Table.1: comparison between costs for 10 different value mutation rate and three of type crossover

Mutation rate	Cost for three kind of crossover		
	MUX	UX	SX
0.02	0.011118	0.011073	0.011308
0.04	0.011164	0.011073	0.011164
0.06	0.011118	0.011026	0.011026
0.08	0.011026	0.011118	0.011159
0.1	0.011118	0.011118	0.011026
0.12	0.011073	0.011073	0.011159
0.14	0.011026	0.011026	0.011026
0.16	0.011026	0.01112	0.011026
0.18	0.011026	0.011118	0.011073
0.2	0.011073	0.011073	0.011026

Table.2: values of duty cycle and inductance for different value of mutation rate with three types of crossover

Mutation rate	SX		UX		MUX	
	L_f (mh)	D	L_f (mH)	D	L_f (mH)	D
0.02	10	0.972	10.31	0.995	10.63	0.995
0.04	10.31	0.987	10.31	0.995	10.31	0.987
0.06	10	0.995	10	0.995	10.63	0.995
0.08	10.94	0.995	10.63	0.995	10	0.995
0.1	10	0.995	10.63	0.995	10.63	0.995
0.12	10.94	0.995	10.31	0.995	10.31	0.995
0.14	10	0.995	10	0.995	10	0.995
0.16	10	0.995	10	0.987	10	0.995
0.18	10.31	0.995	10.63	0.995	10	0.995
0.2	10	0.995	10.31	0.995	10.31	0.995

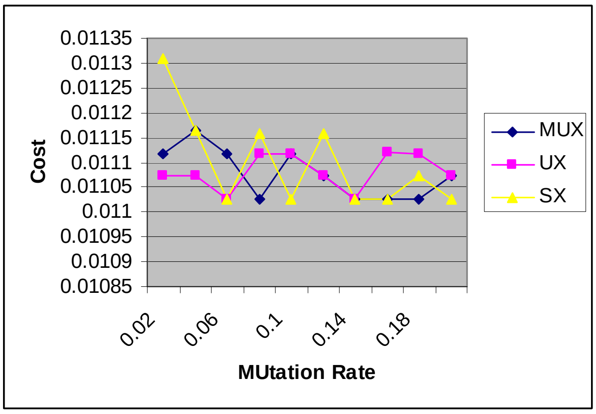

Fig. 4: Comparison costs between three types of crossover versus Mutation rate

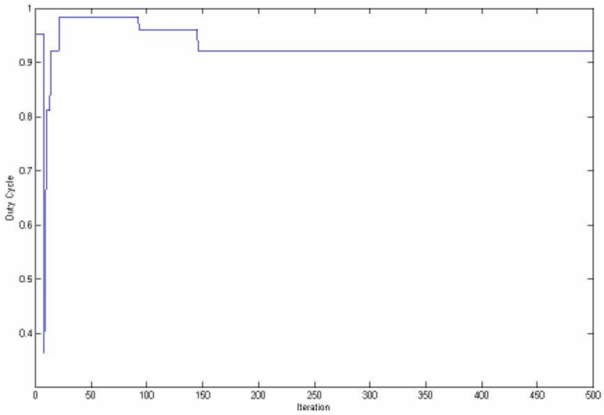

Fig. 5: Evolution of Duty cycle value versus iterations

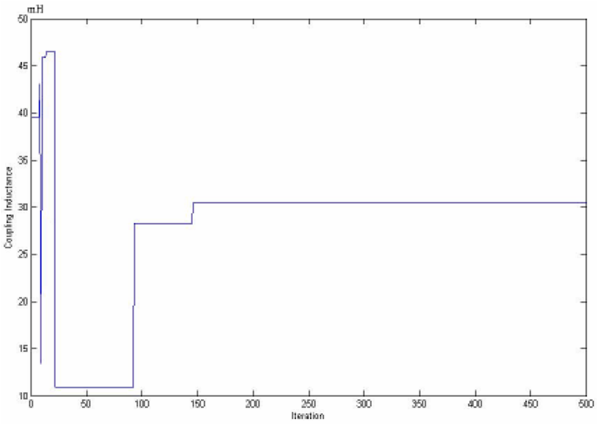

Fig .6: Evolution of coupling inductance value versus iterations

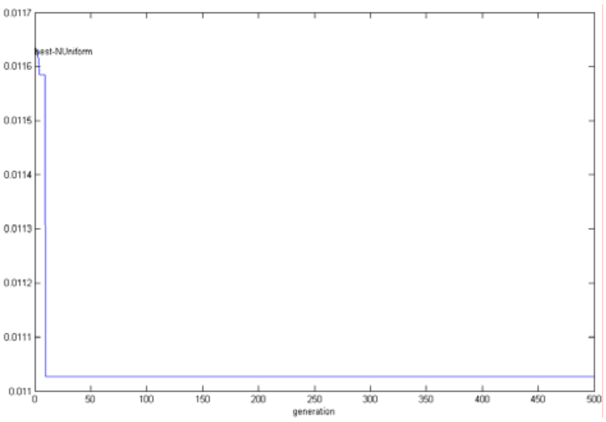

Fig .7: Evolution of cost value versus iterations

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